A ZONE OF WORLDS.

In the latest edition of his collected essays, the many-sided Herbert Spencer considers the problem of that strange zone of small planets which travels between the paths of Jupiter and Mars. With his customary acumen, he considers the relations presented by the ring of small planets, their distribution as regards size, inclination, eccentricity, and so forth; and in the facts thus collected and analyzed he finds evidence that there was once a single planet traveling along the middle of the region now occupied by the zone of asteroids, and that this planet at some remote epoch burst into thousands of minute fragments. Of course, the theory is not advanced as a new one, but the evidence in its favor has never before been so fully presented.

I believe our great philosopher to have arrived at an entirely erroneous conclusion, ably and clearly though he has dealt with the evidence. I shall endeavor to show that while all the evidence offered by Mr. Herbert Spencer is consistent with another interpretation, there is some evidence not touched upon by him which will bear no other explanation than that which I shall indicate. Leaving, however, for the moment both the evidence he has adduced and the theory which I take to be the only one available, I wish at the outset to consider the complex nature of the solar system and the position apparently occupied in it by the asteroidal zone.

Until the Copernican theory was established, astronomers not only did not—they could not—form any idea whatever of the relative sizes of the different planets; for they had no notion of the relative distances of these bodies. Thus men's views as to the nature and character of the several planets were formed in the course of ages, during which it was not known whether Jupiter or Saturn were the larger, or whether Mercury or Venus or Mars might not be very much larger than those planets which we now know to be the giants of the solar system. This was

unfortunate; because, when the Copernican theory was established, and when, later, the telescope showed the globe forms of all the planets and the systems of subordinate bodies which attend upon them, it did not seem to occur to any astronomers to indicate how completely these discoveries modified the aspect of the whole system. Later, other discoveries were made, including the recognition of the zone of asteroids and the discovery of Uranus and Neptune, which should still further have modified the views of astronomers. But settled as men's ideas were in a particular groove, no marked effect was produced; and beyond the suggestion that probably the zone of asteroids marked the place where a single planet had once traveled, astronomers were led to no new thoughts about the planetary system. The planet which was supposed to have burst illustrated, indeed, their unwillingness to change their views; for, by imagining such a planet, they were able to conceive the original condition of the solar system as even more uniform than it had appeared to be, either when as yet none of the asteroids had been discovered or when the asteroids were not explained so conveniently.

Yet every one of the discoveries made by astronomers since the time of Copernicus, including the discovery of the truth of the Copernican theory itself, has given evidence of great variety and complexity of structure within the solar system. The theory of Copernicus, and the light which it threw on the dimensions of the solar system, proved that Jupiter and Saturn are bodies so much larger than the earth, Venus, Mars, and Mercury, that they must be set in a different class. The invention of the telescope, and the discoveries made by its means, proved that Jupiter and Saturn are the centers of systems resembling, though on a smaller scale, the solar system itself. The calculations by which the masses of the planets were determined proved that in mass, as well as in volume, enormous differences exist. The successive discoveries of the ring system of Saturn, of the zone of asteroids, of the small moons of Mars, of the systems of meteors, of planetary comets, and others, point unmistakably to a variety of structure within the solar system such as the earlier astronomers had never imagined. Yet no new survey of the solar system, no new effort to classify its members and to determine if possible their real nature and significance, was ever systematically attempted, or if attempted was held to belong rather

to the region of speculation than of observation,—as though anything could possibly have been more wildly speculative than the belief that the planets are such as they were imagined to be by the astronomers of Ptolemy's school.

Let us try to take such a view of the solar system as probably astronomers would have taken if their first ideas had been formed when they were in possession of the facts which have come to our own knowledge.

In the first place, suppose we could look at the solar system as it might be seen at some given moment, were our powers of vision as keen as those which are given to us by the most powerful telescopes yet made by man. We should see a great, glowing orb, containing more than seven hundred and twenty times as much mass as all the rest of the members of the solar system taken together. Around it travel four bodies relatively very small, at distances which may be represented by the numbers 4, 7, 10, and 16. The largest of these, at distance 10, has a companion body fairly comparable in size and mass with the rest of the group. Around this part of the system travel thousands, or more probably millions, of bodies in the form of a great ring whose entire breadth is greater than the diameter of the earth's orbit. The entire mass of all the asteroids together is not one-tenth the earth's mass. Then, at a distance more than three times as great as that of Mars, we come suddenly on a body entirely unlike any of those yet mentioned. A globe is found more than three hundred times as massive as the earth, and not far from two hundred times as massive as all the planets yet mentioned put together. It is girt round by a system of worlds, comparable rather with Mars and Mercury than with bodies of inferior class. The least of them has a surface equal to North and South America taken together, and is fit, therefore, to be the abode of many millions, nay, rather millions of millions, of living creatures. Oddly enough, the system of Jupiter and his satellites so closely resembles, though of course on a much smaller scale, the system of four bodies, Mercury, Venus, Earth, and Mars, around the sun as center, that a picture of one serves well as the picture of the other.* We next come, at a distance

* Once when an assistant had unluckily broken a lantern slide showing the orbits of Mercury, Venus, Earth, and Mars about the central sun, I for the occasion substituted a slide showing the orbits of Jupiter's four moons about their central planet. No one detected the change.

nearly twice as great from the sun, to a body less, indeed, than Jupiter, but belonging to the same class,—the ringed giant Saturn, a hundred times as massive as the earth, and circled round by eight worlds, the largest of which exceeds Mercury in size, besides a ring system, akin in some respects to the ring of asteroids. Again we pass over nearly as great a distance as we had already reached, and come upon the orbit of Uranus, with his family of four worlds as yet discovered; and though Uranus is much less than Saturn, he is a giant compared with the earth. Lastly, after passing over half the distance at which Uranus travels, we come on the orbit of the most distant planet, Neptune, a giant planet (brother to Uranus, in size and mass), attended by but a single yet discovered moon.

We have so fallen into the habit of regarding this system as represented by a central body with a series of circles set round it, that we find it difficult to picture it as it would appear to one who, visiting our sun's neighborhood from outer space, should view the system as it would appear at any instant of time. He would not recognize that relationship of all the bodies in the system to a central mass, which appears to us the most striking feature of the planetary family. Instead of that, he would see five leading bodies, each attended by a family of small worlds. These five would not include our earth. They would be, first, the sun, attended by five worlds (two of which would be seen to form a double planet), Mercury, Venus, Earth and Moon, and Mars; secondly, Jupiter attended by a family of four worlds; Saturn with eight attendant worlds and a ring system; Uranus with his family; and Neptune with his (for we may well believe that the discovered moon of Neptune has fellows which yet remain to be detected).

In what way would such a visitant of the solar system regard the asteroidal family? He could find nothing analogous to them throughout the five families, except only in the Saturnian system. There he would see a ring, or set of rings, consisting of multitudes of tiny bodies, like sands on the sea-shore for multitude. There can be no doubt, of course, that the Saturnian ring system belongs to Saturn, for it lies within the orbit of the innermost of his eight moons. But the ring system of asteroids, regarding not only the paths of these small bodies but the position of the asteroids at any given instant, as manifestly belongs to the sun; for he lies at the center of the ring. Thus,

our imagined visitor from interstellar space would at once decide that the asteroidal zone belongs to the first of the five leading bodies of the solar system.

Observe that thus viewing the asteroidal ring we find its character altogether natural. It has the features we might expect, after what we have found in the ring of Saturn (there unmistakably), to exist in a ring system appertaining to a leading (in this case, the chief) member of the solar system. Regarded as part of a large system, including the giant planets, attending on the sun as the one great center, the asteroidal zone is altogether abnormal, and in a sense inexplicable. Supposing we could find a natural explanation of the smallness of the inner planets Mercury, Venus, and the Earth-Moon pair; supposing, further, that we could explain the way in which, after showing a gradual increase in size and mass, thus far, with increase of distance from the sun, the system of primary planets next presents a marked falling off in both respects; and supposing, further, that passing from the outside of the planetary system inward toward the center, we could fairly account for the increase from the smaller giants, Neptune and Uranus, to the great ringed giant Saturn, three times as massive as all the just-named planets together, and thence to the still mightier Jupiter, which surpasses in mass Saturn and the rest together two and a half times; yet how are we going to explain the strange anomaly that just inside the track of the prince of all the planets we come to a zone of bodies so insignificant that even if they are regarded as the fragments of a single planet which has burst, that planet could not have had a tenth part of the mass of our earth, and would probably have had a smaller mass than even Mercury?

Thus, while the asteroidal ring, regarded either as a zone of small bodies originally so constituted or as formed by the bursting of what was once a single planet, appears as an entirely abnormal feature in the solar system, it accords quite naturally with other characteristics of that system when regarded as occupying the same position in the sun's special family that Saturn's rings occupy in the Saturnian system. When we consider the solar system as a product of evolution (that is, as developed by processes akin to growth), we find the asteroidal system still more difficult to explain, unless we separate it, along with the sun's family of small planets, from the rest of the

system, and regard it as forming part of the sun's special domain. It is certain that, according to the Nebular theory of Laplace, there ought to be a certain uniformity in the dimensions and masses of the planets, as well as in the arrangement and distances of their orbits. For the process suggested in that theory is a uniform one, acting from the outside of the system where Neptune was made toward the interior where Mercury, the innermost planet, was formed. Uniformity there must have been, though what the law or laws of such uniformity, may not be clear. Now, apart from their utterly abnormal position, as just noted, the asteroids show an utter absence of uniformity in all the details of their system, as well as in their orbital movements. As Mr. Herbert Spencer justly notes, in considering that particular theory of their origin which Laplace himself suggested, if a nebulous ring broke up into numerous small portions revolving around the sun with approximately equal velocities, "their mean distances from the sun could scarcely differ so much that some are twice others; it could hardly happen that the annular space included between their most unlike mean distances would be more than one hundred millions of miles across, and that the space occupied by their widest excursions would be two hundred and seventy millions of miles across"; the parts of such a ring could not show the wide range of orbital inclination seen among the planetoid orbits; there could not be such eccentric orbits as are found among the asteroidal paths, one of which actually passes within the orbit of Mars; and, lastly (though this is indeed not a separate objection, being involved in the consideration of the enormous breadth of the system), "there could not arise any considerable differences between the times in which the discrete portions of such a ring revolved around the sun to the extent of some being thrice others."

These are, however, in the main, objections to the theory of Laplace itself; for it will be found on careful consideration that every process by which a single planet could be formed out of the fragments of what was once a complete ring, would actually require the variety of inclination, eccentricity, and mean distance, which appear thus inconsistent (to the eyes of one of our keenest modern reasoners) with the hypothesis of Laplace. A series of fragments traveling nearly at the same mean distance, in the same plane, and with but slight eccentricity, around even such an orbit as the earth's, could not gather up into a single

mass in tens of millions of years; much less could such bodies traveling around orbital regions as wide as the paths of Uranus or of Neptune.

Of course, to any such theory of the origin of a single planet, from which, by a mighty outburst, the whole system of asteroids was formed, as it were, at a single stroke, there are other and still more striking objections. Those who advocated the theory of a burst planet in the time of Laplace were not greatly troubled by such objections as our Danas and Sterry Hunts, our Scropes and Mallets, recognize in the present day. These, while they know how tremendous may be the local action of the forces which are generated by the contest between the internal heat and the external pressures and movements of the earth, know also that the earth is neither strong enough nor weak enough to be even shattered into fragments by an explosion, such as Olbers, in the confidence of half-knowledge, could calmly enough suggest. For such an explosion to take place, the earth must be, on the one hand, far stronger than she is, to resist the action of such forces as would have to accumulate in order to be able finally to disrupt the whole globe; but on the other hand, the earth would have to be so much weaker than she is as to give way simultaneously at all parts of her crust in the manner conceived by Olbers. The fact really is, that the earth, in the combined strength and weakness of plasticity, is as safe against explosion as though no subterranean energies or external forces of disturbance were at work upon and within her frame. The material which seems to us hard and breakable is absolutely plastic at a depth of less than thirty miles below her surface. It would be so were its substance the best tempered steel. And in this plasticity lies its safety; though, to say truth, the earth is composed of no bursting forces which approach even to one thousandth part of the energy which would be necessary for the shattering of her crust. The chief disturbing force seems to arise from the water which finds its way beneath the surface. This, no doubt, exposed to the heat of the earth's interior, presently assumes the form of superheated steam, and when gathered in sufficient quantities, produces irregular upheavals, earth-shakings, volcanic eruptions, and so forth. But these are forces affecting in reality merely the outer film of the earth's crust. If they gathered in ten times greater amount than in the most terrible earthquakes yet known, the result, disastrous though it might

be to the human race, would not appreciably affect the earth as a whole. And constituted as the earth's inner frame is,—of matter which, however solid, is not rigid, but absolutely plastic,—there is no possibility of the earth's seas finding their way in, in sufficient quantity to seriously affect the real crust (as distinguished from the outer film we can examine), far less the interior mass.

But the explosion theory of the small planets is open to an absolutely fatal objection, the full force of which only the mathematician, perhaps, can appreciate. If a planet could burst, every fragment would start in its independent course from the scene of explosion. Its new path, therefore, however it might differ in eccentricity, inclination, and period from the path of the single original planet, would be a path passing through that point in interplanetary space where the explosion took place. For thousands of years after the explosion, the orbits of all the fragments would exhibit this evidence of their common origin. Perturbations would, of course, in the long run, carry all or most of the paths away from that point; but still it would be possible for the mathematician to recognize the fact that once they had had a common point of intersection. The only class of perturbations with which mathematics could not thoroughly deal would be those arising from their mutual attractions. But even on this point the mathematician has somewhat to say. The masses of the individual members of the asteroidal family are quite unknown. The numbers of the family, even, and their orbital movements, are as yet undetermined. Yet the whole family have been put in the scales of science and weighed, with the result that the entire mass of the zone is less than the mass of the planet Mars. Now the disturbing effect of Mars on the earth, its nearest neighbor, is so very small that it produces scarcely any measurable influence, even in long periods of time. The zone of asteroids is, however, far wider than the interval which separates the paths of Mars and the earth. The mutual influences of bodies spread over so wide a region, and having an average mass certainly less than the three-hundredth part of the mass of Mars, may certainly be neglected in discussing the question whether the orbits of the asteroids ever intersected in one small region, such as the original imagined single planet could have occupied. This done, it is found that these orbits could not have had, at any time, that common region of intersection.

The theory of explosion is therefore as untenable on *a posteriori* as on *a priori* grounds. But perhaps the best disproof of this theory is to be found in the clearness of the evidence which exists in favor of another theory, flowing naturally from the one theory of the origin of the solar system which gives an account of the peculiar way in which the various masses within the solar system are distributed.

It has become clear within the last half century that the interplanetary spaces are traversed by millions of millions of streams of meteoric matter, traveling in orbits of every variety of eccentricity, inclination, and direction (unlike the planets which travel all in one direction around the sun). Our earth passes in her yearly circuit around the sun through the orbits of some four hundred of these meteoric streams, though only through each stream itself of the number when it happens to be passing at the time that the earth crosses its orbit. It has been calculated by Professor Newcomb that in each year about four hundred millions of meteors of all orders, down to the smallest which ordinary telescopes would show, fall on the earth's atmosphere. But the estimate now formed of the number of bodies so encountered is very much higher. All these bodies are eventually received in the form of microscopic dust on the earth's surface. In this lies the proof that the total number of these streams actually existing must be counted by millions of millions, the total number of individual meteors being simply uncountable.

Now, when these enormous numbers of meteoric systems exist, and when it is seen that year by year the earth still gathers in a large mass of meteoric matter (however small the mass may be in comparison with her own), we see that in the remote past the meteoric and cometic tenantry of our surrounding space must have formed a very important part of the solar system. Considering the millions of years proved to have elapsed since the system had its present general aspect, and the tens of millions of years preceding that time, we cannot but admit that the quantity of meteoric and cometic matter which could stand even the present rate of drain during so long a time must have been enormous. But it is obvious that the rate at which the meteors were withdrawn from circulation in far-back times must have been much greater than at present, for the simple reason that it would be proportional always to the number of free meteors,

and this number has been constantly diminishing; and before the planets had assumed their present comparatively compact forms, their sweeping capacities would necessarily have been far greater than at present; for their widely extending, partly vaporous masses would range through much greater regions of the meteor-crowded interplanetary spaces.

Taking all these considerations into account, it becomes clear that no small portion of the present mass of each planet must have been derived from the process of meteoric aggregation. So much is certain. The whole subject of the origin of our solar system is full of difficulties and perplexities; but some few points are quite clear, and among them is this one. But when we take this at least partial meteoric origin of the solar system into account, we find an explanation of those general features of the arrangement of masses throughout the system of which the theory of Laplace gives no account whatever, and amongst those features the asteroidal zone finds its explanation.

Consider the conditions under which the process of aggregation would have gone on in the beginning:

From what we know of the present condition of the meteoric systems, we learn that, from the outset, there must have been a steadily increasing wealth of meteoric distribution with approach toward the sun. So that, were this point alone to be considered, we should expect to find the largest planet traveling next to the sun, and the planets growing less and less with increasing distance from him. But the movement of meteoric bodies around the sun would be more rapid the nearer they drew to him on their eccentric paths; and, apart from eccentricity of orbit, meteoric velocities would be greater near the sun than far away. Thus, at our earth's distance, the average velocity of a meteoric body would be about nineteen miles per second, its maximum velocity about twenty-seven miles. Close by the surface of the sun, the least velocity on a free orbit (necessarily circular, to give the least velocity there) would be about two hundred and fifty miles per second, and the greatest velocity about three hundred and fifty-five miles. At the distance of Jupiter, the maximum velocity would be only about twelve miles per second; less at Saturn's distance; and much less at Neptune's.

Now clearly the growth of a mass by the gathering in of meteoric matter would depend in great degree on the velocity

with which such matter came by it. If its outskirting vaporous matter were actually interposed on the meteor's track, manifestly the chance of intercepting the meteor mass would be small if the velocity of the body were very great. If there were no actual collision at this passage, the power of the aggregating mass to perturb a passing body, and so alter its path as to make its eventual absorption a mere question of time, would depend in great degree on the length of time during which the meteoric mass was in its neighborhood, and this would be greater or less according as that mass moved with less or greater velocity.*

Thus, approaching toward the sun, we find the formation of a planet encouraged by increase of material, but rendered more difficult by increasing velocities. It is evident that there must be some distance at which the conditions would, on the whole, be more favorable than at any other distance, a region where there would be a sufficient quantity of meteoric material, while the motions would not be too rapid to prevent steady aggregation of matter. At that most favorable distance, the largest subordinate aggregation would form. In other words, this would be the region where the giant mass would form from which, millions of years thereafter, Jupiter with his system of attendant worlds was to be developed.

Now, it is clear that, outside the domain where Jupiter was formed, we should find planets less than he, at distances corresponding to the distance separating Jupiter himself from the central mass. Saturn, twice as far as Jupiter from the sun, and much less than he in mass; Uranus, twice as far away as Saturn, and still less than he, would thus be accounted for. And if there were but one more, we can see reasons why that outermost planet, not being disturbed in its growth by a gathering mass yet farther from the sun, would neither travel quite so far from the center as would correspond with the law thus far noticed, nor show any further diminution of mass beyond that shown in the case of Uranus. At least, here seems to reside a not unreasonable explanation of the circumstance that, in the case of Neptune alone, Bode's Law (of distances doubling outward from Mercury's orbit) is found to fail, while his mass is not less

* As it sometimes happens that speculative considerations are advanced in the definite and confident tone which should belong only to statements of fact, I deem it well to point out that what I have stated above is simply matter of fact, not speculative at all.

than that of Uranus, but slightly greater. We may also find, in the exceptional circumstances of the outermost region of the solar system, an explanation of the circumstance that the satellite systems of Uranus and Neptune, only, show a movement of circulation around their primary in a direction contrary to that observed throughout the rest of the solar system,—not only in the movements of the planets around the sun, and of the satellites around their primaries, but also in the rotation of individual planets (including our moon) upon their axes.

Turning to the region inside that swept through by the mighty, gathering mass of Jupiter, we find on the line which we are now following an explanation of what before had seemed mysterious, the singular arrangement of the masses of those smaller planets which seem to own the sun as their special ruler.

It is clear that just inside the track of Jupiter, matter would either aggregate under great difficulties or fail to aggregate at all. His mighty disturbing influence, conjoined with that exerted by the sun, would here produce irregularities of movement akin in a sense to those which affect a sea where two cross sets of waves are traveling; just as in such a sea we find no mighty moving masses of water, but only broken waves, so in the region where the influences of the sun and Jupiter were combined, there could form no great aggregation, but only small pieces of what under other conditions would have been a planet. Be it noticed that the comparison here advanced is not merely metaphorical, as it might seem; it is demonstrable, as a mere matter of fact, that clouds of cosmical dust sweeping around the great central sun, under his influence solely or chiefly, would gather eventually into a single mass, while similar clouds under his influence, combined with a sufficiently powerful thwart influence, such as Jupiter would unquestionably have exerted on the region inside his track, would break up into a flight of small bodies circling on independent orbits around the central sun.

But we shall return presently to this point, and show the very marks which have been left by Jupiter on the asteroidal zone. For the moment we must consider the other members of the sun's special family.

Inside the zone where a planet failed altogether to attain the fullness of independent planetary life, we might expect to find a region where, though a planet formed with difficulty and acquired but a small mass, it yet succeeded, despite the per-

turbing influences of Jupiter, in gathering up its substance and becoming a primary though small member of the solar family. Possibly in the conditions prevailing here we may find an explanation, also, of the circumstance that Mars alone, of all the primary planets, has two bodies attending on him which, though we may call them moons, are in reality far too small to be set in the same class as the moons of Jupiter and Saturn,* and the companion planet of our earth.

On the other hand, in the region nearest to the sun, the velocities of meteoric on-rush would be so great that a planet would form with great difficulty, or not at all. Most probably — if we can judge from observations made during eclipses — no planet such as the Vulcan of our books of astronomy exists in the sun's immediate proximity. But there are good reasons for believing that a number of tiny bodies—pieces of planets, so to speak (unless we prefer to call them, with Humboldt, pocket planets)—travel around him within the orbit of Mercury. These, in the region of greatest disturbance near the sun, would correspond with the zone of asteroids in the region of greatest disturbance near the outskirts of his special domain.

Be this as it may, we certainly find near the sun a planet — Mercury — even smaller than Mars, affording thus evidence that that region is even less favorable for planetary development than the region inside the asteroidal zone, where the planet Mars with his two small moons was fashioned.

* The idea has been advanced that because the smallest of Saturn's moons —Hyperion—required a very powerful telescope and the keen eye of Prof. G. P. Bond to detect it, therefore it may be regarded as comparable in smallness with the moons of Mars. A slight consideration of the circumstances under which these bodies are visible, will show how very much larger Hyperion must be. Saturn's distance from the sun is, roughly, about six times as great as the distance of Mars, and therefore his satellites are illuminated with but about one thirty-sixth part of the light which illuminates those of Mars. When Mars is so placed that his moons are discernible in our telescopes, his distance from the earth is about the twentieth of Saturn's, corresponding to a diminution of the apparent size of Hyperion's disk 400 times greater than the diminution of the disks of Mars's satellites. Thus Hyperion, to appear as bright as one of the Martian moons, must have a surface 14,400 times as great, corresponding to a diameter 120 times as great, and a volume 1,728,000 times as great,— which assuredly sets him in a different class of created orbs. Here I have taken no account of what is assuredly the case,— that Hyperion is certainly a much easier telescopic object than either of the moons of Mars.

Between the planets Mercury and Mars lies a region where the sun's disturbing forces on the one hand, and those of Jupiter on the other, are neither so effective separately as in the regions traversed by Mars and Mercury, nor conjoin their influences disastrously as in the region of the asteroids. Here, therefore, we should expect to find the largest members of the sun's special family; and, accordingly, here we find Venus and the earth, Venus on the solar side less than the earth on the remoter side, just as Mercury is less than Mars.

It is noteworthy, also, how the largest member of the sun's special family, thus formed where the conditions seem most favorable, is attended by a companion body, the only secondary planet, properly so called, in the whole region inside the orbit of the giant Jupiter.

But now I would call attention to the way in which the asteroidal zone presents itself as part of the sun's own domain, in the same way that the Saturnian rings appear as part of the system of that noble planet. Not only are the asteroids thus recognized as occupying a natural position in the solar system, instead of an abnormal and scarcely explicable one, but we shall find on comparing the zones of asteroids with the rings of Saturn, that there is a most remarkable and significant feature common to both, by which not only are they brought into parallelism of condition, but may both be shown to have clearly imprinted on them the marks of the influences under which they reached their present condition.

Observe, I have spoken of the *zones* of asteroids, using the plural here for the first time. The description is correct, though no one would imagine it who should either look down a list of the minor planets with their mean distances, eccentricities, inclinations, and so forth, or should look at a picture presenting their paths as they really are. It required the keen insight and patient labor of Professor Kirkwood (of Bloomington, Ind.) to sift out from what seems a meaningless confusion of orbits the evidence of zone formation, which, though thus veiled, is clear and convincing enough so soon as the veil is lifted.

The asteroids, when duly arranged in the order of their mean distances, are found to be separable into distinct zones. At certain mean distances there are no asteroids at all, at others scarcely any; while at mean distances between these vacant or comparatively vacant zones, asteroids abound. This would be a

remarkable circumstance, even though no law could be detected in the arrangement and dimensions of these zones,—a circumstance not less striking than the existence of dark bands and zones in the solar spectrum. But as in this latter case the interpretation of the dark bands was of far greater importance than their mere detection, so is the interpretation of the vacant zones in the asteroidal region a matter of even more significance than their recognition. They lie at those very distances from the sun at which the perturbing action of Jupiter would be greatest. We know from the theory of planetary motion that when the movements of one planet synchronize with those of another, much greater perturbations arise from the mutual attractions of the two bodies than where there is no such harmonious relation existing. Thus Jupiter and Saturn disturb each other so effectively, owing to the simple relation between their orbital movements—two circuits of Saturn synchronizing almost exactly with five of Jupiter, the result being an irregularity of motion which long before it was explained was called the great irregularity of Jupiter and Saturn. Saturn is most affected, being the smaller; and if he were very small, Jupiter would scarcely be affected at all, but the supposed small Saturn greatly. Now, among the particles of clouds of cosmical matter traveling where the zones of asteroids now lie, would be many having periods synchronizing with Jupiter,—for instance, the region would include bodies traveling in one-half, two-fifths, three-quarters, two-thirds, three-sevenths, and four-sevenths of the period of Jupiter. These he would most effectively disturb, and would work out of their paths into regions traversed by bodies on either side not having periods so dangerously (for them) synchronizing with his. So would he sweep clear, as it were, those mean distances; and in the fullness of time (a few tens of millions of years) no cosmic dust would remain there. Hence would have arisen the state of things shown by Professor Kirkwood—the Kepler of modern astronomy—to exist in the asteroidal region. Nor is it easy to conceive any other way in which this remarkable feature of the family of asteroids can be explained.

But if this explanation is the correct one, we might fairly expect to find in the Saturnian rings system something akin to it. Now, not only is this the case, not only are the tiny satellites which form these rings cleared away precisely where the disturbing action of the Saturnian satellites would be most

effective, but in their case the clearing away, instead of requiring the careful inquiry of a Kirkwood to reveal it, has been recognized for more than two centuries as a marked feature of the Saturnian system. The great division commonly called Ball's division, but really discovered by the elder Cassini, is simply the chief cleared space. It is all but absolutely clear of satellite dust to a width of about a thousand miles,—not quite clear, for some little light comes from what was called erroneously the black division. Elsewhere are other divisions, not so broad nor so dark, but like the great division, corresponding to the distance from Saturn's center, where the perturbing action of the nearer satellites would be most effective. Here, too, though the divisions were discovered with the telescope, we owe to Professor Kirkwood their simple and most beautiful interpretation.

No doubt then can remain. The asteroidal zones, though they may present, as Dr. Whewell quaintly put the matter, a case in which a planet has been spoiled in the making, yet show clearly the marks of their origin. They belong as certainly to the sun's special family of small planets, as the rings of Saturn belong to the Saturnian system. They bear, like these rings, the marks of the action of the other orbs which travel round their ruling body. They not only tell us of their own origin, but of the processes by which planets not spoiled in the making have been fashioned. They speak, moreover, of æons of æons of past time, during which the mighty action of Jupiter (already formed, be it noticed, and therefore telling us also of enormous antecedent periods of time) was at work upon them, clearing out the zones where asteroidal movements harmonized too closely with his own. Here, therefore, we may say that in this neglected wilderness of small worlds, we

> "Have come on that which is, and caught
> The deep pulsations of the world,—
> Æonian music measuring out
> The steps of time."

RICHARD A. PROCTOR.